4.0 DISCUSSION

The primary criteria specified by the ACOE, Portland District, Oregon for this study were met for the initial two test conditions (spillbays 3 and 4). The same criteria established for the third test condition (spillbay 6) by the Walla Walla District, Washington, after the initial study had started were also met. These were: recapture rates of tagged fish to exceed 80%, recapture times ≤1 h, handling mortality ≤10%, precision (ε) of the survival estimate to be within ≤±5% at the 90% probability level, the characterization of injuries, and fish condition. The realized recapture rates of treatment (both alive and dead physically retrieved) were >94%; the average recapture times of treatment and control groups were <10 min; the immediate assumed and observed control mortality was <5% with no fish mortality during the 48 h period; and the precision (ε) on both the immediate (1 h) and 48 h estimated survival rates was <±5%, 90% of the time. Only one targeted species (chinook salmon) was involved in this study, no non-targeted species were handled. The study succeeded in identifying the location and type of fish injury. Finally, the use of balloon tag-recapture technique identified a potential fish passage problem in the downstream area of the spillway and within the powerhouse ice and trash sluiceway.

All recaptured fish were examined immediately upon recapture and at 48 h for external injuries. Those which died were also necropsied to examine for internal injuries. This examination procedures proved efficient for assessing passage-related injuries for alive fish while still maintaining the fish in a vigorous condition.

The following explicit assumptions were made: handling, tagging, and release do not differentially affect survival rates of treatment and control groups; recapture probabilities for the treatment and control groups are the same; and recapture boat crews do not differentially select retrieval of either group of fish. These assumptions were considered satisfied as follows. The differential effects of handling, tagging, and release were not evident on recaptured fish held for 48 h in any test scenario. No mortality of recaptured fish occurred in either the treatment or control group (100% survival) for the spillbay tests. The potential bias due to non-selective retrieval of treatment and control groups was minimized by not assigning a specific boat crew to retrieve either treatment or control group fish. Any of the crew that was available for fish recapture was assigned the task of individual fish retrieval. The recapture boat crews were trained in fish handling and retrieved the buoyed fish with minimal damage. The average recapture times for the treatment and control groups were similar.

The assumption that the treatment and control group fish were equally vulnerable to recapture was not statistically violated, though some variation between trials within treatments and control occurred. Much of the variation appeared to be due to loss of fish among the concrete baffles and a 13 ft high vertical end sill located downstream of spillbays. It was suspected that the tagged fish may have become entangled in, or collided with these energy dissipation structures. Stationary radio transmitter signals received from this area appeared to strengthen this suspicion. Tag malfunction was ruled out as a source of variation because of the use of two tags; loss of both tags on a fish has been rare in any of the previous studies to date.

One of the considerations for the study was to minimize the number of fish used for each experiment without sacrificing precision. Mathur *et al.* (1996a) proposed that a sample size of 250 fish (treatment and control each) may be adequate for achieving a precision (ε) of $\leq\pm5\%$, 90% of the time, if the recapture and control survival probabilities exceed 0.95. This combination was achieved in the present study, the sample size used (270 to 271) for the two treatments with a common shared control of 230 fish was deemed adequate. For the overflow weir test, a release of 210 treatment and 105 matching control was also adequate to achieve the anticipated precision (ε). The release of a common control group of fish for two simultaneous treatment releases on the same day further reduced the need of additional fish without sacrificing precision. This finding is similar to that observed for the turbine passage survival research on chinook salmon at Lower Granite Dam (Normandeau Associates *et al.* 1995). A recently completed fish spill survival and condition study at Bonneville Dam showed similar results, thus strengthening this conclusion (Normandeau Associates *et al.* 1996). Consistency in these results suggests that if the fish supply is limited, it is possible to achieve the anticipated precision using fewer controls if simultaneous evaluation of more than one treatment effect is desired.

The principal causal mechanism for injury/mortality to fishes transported via spillways have been attributed to shear forces, turbulence, rapid deceleration, terminal velocity, impact against the base of the spillbay, scraping against the rough concrete face of the spillbay, and rapid pressure change (Ruggles and Murray 1983). However, experiments have not been conducted to identify the relative importance of these factors in affecting fish condition/mortality. Injuries sustained included eye damage, embolism, hemorrhaging, and abrasions (Ruggles and Murray 1983). Although the number of injured fish was relatively small in all experiments at The Dalles Dam the study succeeded to a certain extent in identifying the probable sources of injury/mortality. The scrape and bruise wounds could have been caused by the fish physically contacting structural components of the spillbay, including the tainter gate, and/or contacting the baffles, large boulders, and end sill in the stilling basin. Hemorrhaging and bulging eyes were most likely strike-related as well. Although bulging eyes have been attributed to pressure effects the absence of other corroborating symptoms on necropsied fish (e.g., expanded or burst air bladders, entrapped gas bubbles, etc.) suggests that pressure change was not a probable cause (Cramer and Oligher 1964). Which of the various structural or other components in the spillbay and the stilling basin that contribute most to injuries was not possible without the benefit of a detailed visual examination of the area.

The type and magnitude of injury exhibited by juvenile salmon at The Dalles Dam were slightly different than those observed at Bonneville Dam (Normandeau Associates *et al.* 1996). At Bonneville Dam fish were passed through two spillbays; one equipped with flow deflectors and the other without flow deflectors. Injury rates observed at Bonneville Dam ranged from 1.8% (flow deflector) to 2.2% (without flow deflector). Eye injuries were most prevalent at the flow deflector spillbay while bruises and fin damage occurred at spillbay without flow deflectors. At The Dalles Dam, injury rates ranged from 0.5% (unmodified spillbay) to 2.5% (overflow weir); most were eye injuries or bruises. The baffles and vertical end sill downstream of the spillbay likely contributed to some of the injuries at The Dalles.

Differences in spillway configuration, presence or absence of baffles or flow deflectors, hydraulics, species, and tag-recapture methodology may provide variable estimates of survival probabilities that are less than the ideal 1.0 (Schoeneman *et al.* 1961; Ledgerwood *et al.* 1990; Heisey *et al.* 1993; Normandeau Associates *et al.* 1996). The estimated survival probabilities in the present study (0.955-0.99) are within the range reported by others. Schoeneman *et al.* (1961) reported spillway passage survival probability of 0.98±0.02 (95% confidence intervals) for chinook salmon at McNary Dam and Big Cliff Dam (head 90 ft) on the Santiam River; their estimate was based on pooled data from the two sites due to statistical similarity. Heinle and Olson (1981) reported a survival probability of 0.996 for coho salmon (*Oncorhynchus kisutch*) in passage over the spillway at Rocky Reach Dam on the Columbia River (about 228 mi upstream of Bonneville Dam, 90 ft head). A spillway flow deflector effect study at Lower Monumental Dam on the Snake River (river mile 42, net head 85 ft) did not reveal differences in survival of chinook fingerlings at two spill rates tested (2,800 cfs and 13,000 cfs); the estimated survival, as determined from downstream recovery ratios of treatment and control fish at McNary Dam (about 46 miles upstream of the Bonneville Dam, net head 90 ft), was 84% at 2,800 cfs and 83% at 13,000 cfs (Long *et al.* 1972). Ledgerwood *et al.* (1990), in a long-term comparative survival study of juvenile chinook salmon in passage through various exit routes at Bonneville Dam, estimated spillway passage at 1.0. All these studies involved a tag-recapture process (e.g., freeze branding, coded wire tags) that occurred over several days and long distances; these studies were not designed to separate direct and indirect effects of spillway passage. A recent study (Normandeau Associates *et al.* 1996) at Bonneville Dam estimated survival probability of chinook salmon at 1.0 in passage through spillbays equipped with flow deflectors and without flow deflectors. The survival probability of Atlantic salmon smolts in passage through ice-log sluices (direct effects) at two hydro dams on the Connecticut River was reported at 0.96 (Heisey *et al.* 1993); the heights of sluices were 52 to 67 ft.

The lowest survival probability (0.955, 90% CI=0.927-0.983) was observed at the unmodified spillbay 3. However, this was primarily due to one treatment trial in which an unexpectedly higher proportion of fish (5 of 30 or 0.167) either became entrapped downstream or the tags became dislodged (both categories are assumed dead in the analysis). This suggests that not all fish traversed the same path after exiting the release hose. The prevailing turbulence and associated hydraulic conditions may have influenced the fish distribution. Some hydraulic conditions in the vicinity of the baffles could increase the incidence of contacting these structures.

The potential effects of baffles and the vertical end sill downstream of spillbays masked the isolation of differences in observed survival probabilities and injury rates due to the modifications at the spillbays and spill volume. Although the estimated survival probability was about 0.038 higher at spillbay 4 (I-slot configuration) than at the unmodified spillbay 3 (10,500 cfs spill), the spillbay 6 (overflow weir) survival was 0.99 (90% CI=0.951-1.0) with a lower spill volume (4,500 cfs). As stated earlier, much of the difference in survival estimates may be due to suspected entrapment of fish in the baffle area, as evident from stationary radio transmitter signals.